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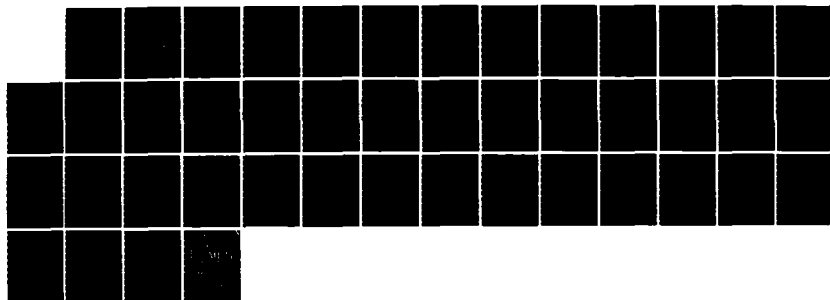
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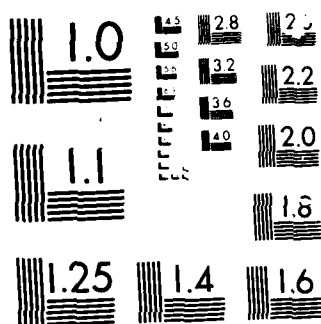
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Logistic regression not only confirmed the group difference but demonstrated an interaction with verbal-sequential skills. High performance on these skills helped the odds of being winged for aviators with low visuospatial ability but hindered those with high visuospatial ability.

Distribution of visuospatial scores for the 2 groups demonstrated reasonable cut-off points at which considerably more drop-outs than winged aviators could have been eliminated. However, these data are relevant only for the selected sample of aviators accepted for the training programs. An additional study on the entire group of applicants including those rejected would allow comparison between the special cognitive tests used in this study and those already used as selection criteria.

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**THE IMPORTANCE OF SPECIALIZED COGNITIVE  
FUNCTION IN THE SELECTION OF MILITARY PILOTS**

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**Running Head: Cognitive Function and Pilot Selection**

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## ABSTRACT

Visuospatial skills significantly distinguished student Naval aviators who dropped out of aviation training from those who received their wings. While both groups were better than average on these tests, the winged aviators were better than the dropout group by 0.25 standard deviation which is highly significant ( $p < 0.0001$ ) for the total sample of 600 subjects. Performance on verbal-sequential skills did not distinguish between the groups.

Logistic regression not only confirmed the group difference but demonstrated an interaction with verbal-sequential skills. High performance on these skills helped the odds of being winged for aviators with low visuospatial ability but hindered those with high visuospatial ability.

Distribution of visuospatial scores for the 2 groups demonstrated reasonable cut-off points at which considerably more drop-outs than winged aviators could have been eliminated. However, these data are relevant only for the selected sample of aviators accepted for the training program. An additional study on the entire group of applicants including those rejected would allow comparison between the special cognitive tests used in this study and those already used as selection criteria.

## THE IMPORTANCE OF SPECIALIZED COGNITIVE FUNCTION IN THE SELECTION OF MILITARY PILOTS

The use of specialized cognitive function in predicting success in task performance has had limited success. On the negative side, it has been shown that a cognitive profile favoring visuospatial skills is typical of learning disabilities [Harness, Epstein & Gordon, 1984] and poses risk for reduced achievement scores in regular school children [Gordon, 1984]. In both these studies, the issue of intellectual capacity has been partialled out suggesting that at least some of the variance is related to the cognitive profile itself. This is important because it raises the possibility that individual differences in performance ability may be related to performance on specific cognitive processes in addition to overall level of ability.

A few subject groups have been tested to see if their career choice or occupation relates in any way to cognitive preference. Individuals favoring verbal-sequential skills have been found to be over-represented in a sample of managers in a health care facility and among the staff of a personnel office in a bank [Gordon, Charns, & Sherman, 1986]. By contrast over-representation of individuals favoring visuospatial skills has been found among airport managers of a major airline and among system programmers in a university central computing facility [Gordon, Charns, and Garamoni, 1984]. These results do not necessarily imply a cause and effect relationship nor that these individuals excel in their jobs but it may be that certain occupations may be more likely to attract individuals with a particular cognitive profile.

One demonstration of the importance of visuospatial function for excellence of task performance was in its correlation with the success for completion of the combat training program by Israeli Air Force trainees [Gordon, Silverberg-Shalev, & Czernilas, 1981]. In that study, pilots who remained in the combat training squadrons were significantly better on visuospatial tests than those who had been forced out of the combat squadron due to lack of ability. Additionally, it was found that pilots who were judged by their flight instructors to be "natural" pilots were likely to be those who performed the best on the visuospatial tests. Verbal-sequential tests did not seem to distinguish good flight performance.

There were no claims from that study that visuospatial skill accounted for all the factors of combat pilot excellence. Certainly health, motor skills and personality characteristics play major roles. Nevertheless, in spite of careful screening procedures used as standards for selection into the pilot training program, visuospatial tests were additionally predictive of success. If these results can be replicated, they strongly suggest that incorporation of the cognitive tests into current selection methods may reduce the attrition from flight school training.

Accordingly, subjects for the present study were student Naval aviators enrolled in ground school or early in flight training. Tests of specialized cognitive function were administered and then the careers of the students were followed in the expectation that the visuospatial tests will again identify potential failures. The sample population was already pre-selected through standard Navy procedures and expected to have the best chance to succeed in the training program from among potential applicants to flight school. Neverthe-



less, a logistic regression model was used on this restricted group to determine the existence of additional predictor variables among tests of specialized cognitive function and to stipulate the odds of successfully completing versus leaving the training program. Significant prediction should encourage a prospective study of applicants prior to selection.

## METHODS

### *Subjects*

The subjects were 600 student aviators who were tested in ground school or during the initial stages of flight training to become Naval pilots. Most were men (98%). Handedness was obtained by having the subjects report "which hand they used most of the time for most things". If right and left hands were to be used interchangeably, then the subject was to report, "both". One-eighth of the subjects reported themselves to be non-right handed: 11% left, 1.5% both.

All subjects were college graduates either from the Naval Academy or other colleges. In addition, all candidates for pilot training had already passed academic qualifying tests including a specially-designed spatial test as well as physical screening examinations. It is known that these tests are used to determine which students could be admitted to the program, but the specific criteria were not available.

## *Cognitive Testing*

The Cognitive Laterality Battery (CLB) consists of 2 sets of subtests. One set of 4 tests assesses visuospatial abilities; the other, verbal-sequential abilities. A factor analysis on a normative group of 250 adults (as well as 750 children) [Gordon, 1986] has confirmed the existence of these 2 main factors.

The tests are presented by projecting 35mm slides onto a screen while audio tapes provide prerecorded instructions and automatic slide advancement by means of a sound/sync projector. Responses are written on prepared answer sheets. Two other tests of general ability were adapted for slide presentation and presented after the CLB: the Symbol Digit Modalities Test [Smith, 1963] and the Standard Progressive Matrices Test [Raven, 1958].

Visuospatial Tests. a) Localization: An "x" appears within a rectangle on the screen and must be marked exactly in the same place in a blank rectangle on an answer sheet. The score is the linear error for 24 trials. b) Orientation: Two identical and 1 mirror image cube constructions [Shepard & Metzler, 1971] are presented in spatial rotation. The subject selects the 2 identical constructions. Max = 24. c) Touching Blocks [MacQuarrie, 1953]: In a construction made up of 8-10 rectangular blocks, the number of blocks touching a designated block must be reported. Max = 30. d) Form Completion: Incomplete silhouette drawings [French, Ekstrom, & Price, 1967; Thurstone & Jeffrey, 1966] must be identified. Max = 24.

Sequential and Verbal Tests. a) Serial Sounds: Familiar sounds (e.g. bugle, baby, bird,...) are presented in sequences of 2-7 in length which are to be written in the same order. Scoring favors

long sequences and allows partial credit. Max = 290. b) Serial Numbers: Number sequences 4-9 in length are presented for recall and scoring like Serial Sounds. Max = 378. c) Word Production, Letters: The maximum number of words must be listed in 1 min. that begin with a given letter. The score is the sum of 3 1-min. trials with different letters. d) Word Production, Categories: Same as Letters, except that words in a category must be listed. The score is the sum of 2 1-min. trials with different categories.

Symbol-Digit Modalities Test [Smith, 1963]. Non-verbal symbols are paired with the digits 1-9 and presented on the screen. The subject's answer sheet consists of the symbols over blank boxes. The task is to fill in as many boxes as possible in 90 sec. according to the key on the screen.

Standard Progressive Matrices Test [Raven, 1958]. A pattern is given in which a piece is missing. The subject must select the correct piece from 6-8 choices. Only sets B-E (48 trials) were given, one at a time on the screen; timing for each trial was fixed according to results of a preliminary study.

#### *Procedure*

All subjects were tested in groups averaging in number between 30 and 50. The room was a large classroom in which the lights could be slightly dimmed to allow comfortable viewing of the cognitive tests presented on a large projection screen in front of the room. The entire testing session required 90-100 min. including rest periods.

Prior to testing, consent forms were read to the subjects and then signed by those who volunteered. Less than 1% declined to be tested. Demographic information including birth date, sex, handedness, and prior flight experience was obtained.

### *Scoring*

Each test was hand-scored and rechecked for errors by at least 2 trained scorers. All tests had been previously normed on a combination of non-college and college samples including graduate and undergraduate students, males and females [Gordon, 1986]. Sex differences were found in all the normative groups so separate norms were used for males and females. Accordingly, z-scores were calculated for all tests so that they could be combined according to the 2 main factors: visuospatial and verbal-sequential which were designated A and P to represent the historical terms, Appositional and Prepositional [Bogen, 1969].

Combining the tests into 2 factors focuses attention on each of them and allows a classification of subjects based on a cognitive profile. The visuospatial score, A, is the average of the 4 visuospatial tests and the verbal-sequential score, P, is the average of the 4 verbal-sequential tests. The cognitive profile, termed Cognitive Laterality Quotient (CLQ), is defined as the difference between the 2 averaged measures:  $CLQ = A - P$ . Overall performance, Cognitive Performance Quotient, CPQ, may be given by the average of all the tests:  $CPQ = A + P/2$ .

## RESULTS

Of those tested, 130 subjects (22%) dropped out or were forced out of the aviation training program. Most subjects of both groups, the drop-out group ("attrites") and the aviators who received their "wings", had cognitive profiles in which they performed better on the visuospatial tests than on the verbal-sequential tests. But the winged group was significantly better ( $p < 0.0001$ ) on the visuospatial tasks than the drop-outs. The difference between the groups was about 0.25 standard deviation.

These results are illustrated most clearly in the distribution of the averaged visuospatial scores for the 2 groups (Figure 1). While the curves are not much different at the upper end, they differ considerably at the lower end. Theoretically, these results suggest that if student aviators in the entering class had been further screened based on a below/above average split on the averaged visuospatial score ( $A=0$ ), 22% of those who eventually left the program would have been eliminated while only 7% of those winged would have been eliminated. It can be seen from the Figure that the mean visuospatial ability for the drop-out group -- the group with the lower visuospatial score -- was positive (better than average) relative to the normative population ( $A=0.420$ ). If this value had been used as the cut-off point instead of the normative average ( $A=0$ ), 52% of the drop-outs would have been eliminated as compared to 28% of the winged. There is no criterion by which to set the boundary point, but these results suggest that a second elimination of admissions to aviation training at a cut-off point near the normative average for visuospatial ability would have affected considerably more eventual attrites than winged aviators.

--Place Figure 1 about here--

The verbal-sequential tests did not distinguish between the two groups suggesting visuospatial skills alone could be useful in predicting successful completion of the flight training program. It is worth noting that while this result should not come as a great surprise, the fact is that the 2 groups were differentiated by their average visuospatial performance scores after selection by the Navy's standard screening procedure. It should also be mentioned that the groups differed significantly in the same direction for each of the 4 tests but that the factor as a whole provided the strongest differentiation.

The group difference on visuospatial skills was a planned comparison since it was expected from previous results [Gordon et al. 1982. However, a logistic regression model was developed in order to assess the association between the specialized cognitive measures and the probability of attrition<sup>1</sup>. Accordingly, a measure of odds of completing the program as a function of cognitive performance can be determined.

For the purpose of analysis, it was assumed that for a given setting of covariates including demographic as well as cognitive tests, the frequencies of attriting aviators follows a binomial distribution. This requires the attrition outcomes to be regarded as independent observations taken with replacement from some large conceptual population of potential aviators. The logistic model was chosen to measure the association between covariates and the probability of attrition because of the model's restricted range for the response probability and because of the simple interpretation of a

logistic difference as a logarithm of an odds ratio [Cox, 1970, McCullagh, & Nelder, 1983; Kleinbaum, Kupper, & Chambless, 1982].

The conditional probability of being attrited given that an individual possesses the covariate values  $x = x_1, x_2, \dots, x_k$  is denoted as follows:

$$(1) \quad P(x) = \text{pr}(\text{attrite} = 1 \mid x_1, x_2, \dots, x_k)$$

The model equation is

$$(2) \quad g\{P(x)\} = C + \sum_{k=1}^k B_k x_k$$

where  $g$  is the logistic function

$$(3) \quad \text{logit} \{P(x)\} = \log (P(x) / (1 - P(x)))$$

Each model was fit to the data using maximum likelihood estimation. Likelihood ratio statistics are used to assess the adequacy of the fit of each model. A Wald test is used to detect the presence of a variable after adjusting for other variables entered into the model. The procedure CATMOD of the statistical program SAS [1985] was used to fit the models.

#### *The statistical model for flight school success*

The first step of the model fitting strategy [Kleinbaum et al., 1982] is to identify extraneous variables that might alter the relationship between the tests of specialized cognitive functions and flight school success. Extraneous variables or covariates include both categorical and continuous demographic variables such as handedness or number of previous flight hours as well as scores on other performance tests. The second step of the analysis is to locate and include in the model the interaction terms that indicate one or more of the covariates alter the association between the significant cognitive variables and attrition from the program. The last step in

the model fitting is to identify confounding variables considered predictive of flight school success whose control would help to reduce the bias in the estimation of the odds of flight school success.

Two models are entertained. The first, Model I, is the more parsimonious in that it eliminates any confounding variable with a predictive contribution whose significance is greater than 0.05. Accordingly, only the visuospatial variable, A, was significantly predictive of flight school success. However, the hierarchy principle requires retention of the verbal-sequential variable, P, because it is involved in the two-factor interaction, A x P ( $p = 0.0295$ ) which was included in the model. No 3-factor interactions were discovered.

Model I:  $\text{logit } P(x) = B + B_1 A + B_2 P + B_3 A'P$  (See Table 1)

The other model (Model II) retains a couple of confounding variables, handedness (HAND) and the Symbol Digit Modalities Test (SYMDIG), because of the theoretical intention of obtaining more valid parameter estimates. In exchange for a more valid estimation there is a slight loss in precision due to the inclusion of additional variables [Kleinbaum et al., 1982].

Model II:  $\text{logit } P(x) = B + B_1 A + B_2 P + B_3 \text{HAND} + B_4 (\text{SYMDIG}) + B_5 A'P$  (See Table 1).

The likelihood ratio, goodness-of-fit statistic is  $p = 0.47$  and  $p = 0.51$  for Models I and II, respectively. This indicates the models cannot be rejected and the conclusion is that they fit the data. Note also there is very little difference in the 2 models because the extra variables retained contribute little to the variance.



- PLACE TABLE 1 ABOUT HERE -

It should be mentioned that one of the general performance tests, Raven's Standard Progressive Matrices, was not included in the second model. It completely failed to contribute to the prediction of attrition. The reason for this may be attributed to a possible association with the Navy's own preselector variables which had been used to select this population in the first place. But if this is indeed the case, it is noteworthy that the effects of the CLB scores under study were not lost because of any association with the Navy's preselectors. This suggests that the CLB scores in the model may be useful in augmenting the Navy's current selectors. The model-based parameter estimates for both models are given in Table 2.

- PLACE TABLE 2 ABOUT HERE -

*The Association between Visuospatial Ability and Flight School Success*

Both statistical models suggest the existence of an association between the visuospatial score, A, and success in flight school. However, the presence of the visuospatial by verbal-sequential interaction (AxP) also suggests that the prediction of success by the visuospatial factor changes as the verbal-sequential score changes. In particular, the visuospatial score predicts better for the lower verbal-sequential scores than for the higher ones.

The following example illustrates how the visuospatial variable is used according to Model I to predict success for various values of verbal-sequential scores. The strategy is to observe the odds of being winged for different values of the cognitive variables. Sup-

pose Student #1 scores poorly (in the 5th percentile) on the verbal-sequential tests,  $P = -0.699$ , but obtains the median visuospatial score,  $A = 0.644$ . According to the model, the odds of being winged relative to being attrited is estimated to be

$$\begin{aligned}\hat{p}(\text{winged})/\hat{p}(\text{attrited}) &= \exp (.674 + 1.153A + .449P - .684AP) = \\ &\exp (.674 + 1.153*.644 + .449*-.629 - .684*.644*-.629) \\ &= 4.10\end{aligned}$$

Therefore, a student with this cognitive profile is more than 4 times more likely to be winged than to be attrited.

Now suppose student #2 also scores in the 5th percentile on the verbal-sequential test, but scores 1.0 standard deviation ( $SD = 0.499$ ) below the median on the visuospatial test,  $A = 0.145$ . Using the same model, the odds between being winged and being attrited is only 1.86. Although the second student has a nearly 2 to 1 chance of becoming winged, the odds of being winged is more than twice as large for the first student than for the second student.

This comparison of success odds can be made explicit by taking their ratio and forming the association termed the odds ratio or cross-product ratio ( $\text{Odds Ratio} = 4.10/1.86 = 2.20$ ). In this example, the odds ratio is interpreted to mean that increasing the visuospatial score by 1 standard deviation is associated with a doubling of the odds of being winged. More precisely, the odds of becoming winged are 2.2 times greater for the student with the higher visuospatial score than for the student with the lower visuospatial score.

The visuospatial flight-school success association, as measured by the odds ratio, varies depending on the specific verbal-sequential

level. The adjusted odds ratio reflects the adjustment for each level of verbal-sequential skill. Increasing the verbal-sequential score from the 5th percentile to the 95th percentile dramatically reduces the ratio of odds of being winged, the adjusted odds ratio, for students whose visuospatial scores remain 1 standard deviation apart (Figure 2). As the verbal-sequential score increases, the odds ratio approaches one, suggesting the students with good verbal sequential scores were not as much disadvantaged for a lowered visuospatial skill.

- PLACE FIGURE 2 ABOUT HERE -

By contrast, the odds ratios comparing students that differ by 1 standard deviation in verbal-sequential skill are plotted for various levels of visuospatial skill (Figure 3). For the most part, the confidence intervals contain 1 (Table 3), suggesting there was no significant difference in the odds of being winged, associated with increased verbal-sequential ability. Indeed, it can be seen that the individual with the higher verbal sequential skill tends to have less of a chance of being winged than the paired individual with the lower verbal-sequential score in the case of high visuospatial performance. This is consistent with the tests of results for the P and AxP terms in the model.

- PLACE FIGURE 3 ABOUT HERE -

Approximate 95% confidence intervals for the adjusted odds ratios are displayed in Table 3. A value of 1.0 for an odds ratio indicates that altering the cognitive variable is not associated with different odds of being winged, and hence signifies no association

between the cognitive variable and being winged. Confidence intervals that contain the value 1.0 represent significant association.

- PLACE TABLE 3 ABOUT HERE -

Although examination of the adjusted odds ratios summarizes the association between cognitive scores and aviation success, it does not expose the levels of the cognitive profile at which students are at the greatest risk of attrition. For the purpose of personnel selection, knowledge of high-risk profile levels is important, and needs to be explored in more detail.

#### *Aviation Success and the Cognitive Profile*

The relationship between the cognitive profile and aviation success may be summarized by plotting the adjusted odds of being winged against various percentiles of visuospatial skill (Figure 4) and against levels of verbal-sequential ability (Figure 5). Each plot of the adjusted odds is made at three fixed values of the other cognitive variable. It is clear that students with the lowest scores on the cognitive tests have the smallest odds of being winged and hence are at greatest risk of attrition. Furthermore, it can be seen (Figure 4) that regardless of the verbal-sequential ability, P, the odds of being winged increases with visuospatial skill. This increase, however, is most pronounced at lower levels of P where students are at greatest risk. By contrast, the odds of being winged are only moderately enhanced by increased verbal-sequential ability (Figure 5) when the student possesses low visuospatial skill, and is again at high risk. Otherwise, increased verbal-sequential ability contributes nothing to the odds of being winged at average visuo-

spatial skill, but actually predicts a *decrement* in the odds of being winged for the high values of visuospatial skill.

- PLACE FIGURE 4 ABOUT HERE -

- PLACE FIGURE 5 ABOUT HERE -

This last puzzling finding concerning the effect of the increased verbal-sequential skill at high levels of visuospatial ability cast suspicion on the validity of the model in this region of the cognitive profile. To check the validity of the prediction of regression model according to the observations in the data, the distributions of visuospatial and verbal-sequential scores were divided into thirds and the proportion of winged vs attrites were plotted for each of the 9 (3x3) cells (Figure 6).

- PLACE FIGURE 6 ABOUT HERE -

The theoretical odds are the ratio of the expected number of winged students over the expected number of attrites. These are computed by summing the predicted probabilities of being winged or attrited for students belonging to a particular cell. It can be seen that the predicted and observed ratios are reasonably close in magnitude and direction. The fewer winged subjects predicted for subjects with high verbal-sequential and visuospatial skills was actually present in the data thus allaying the fears of invalidity in this region. Only the middle cells had the most deviant ratios. This suggests a difficult-to-interpret quadratic effect for the model. However, inclusion of the quadratic effect in another model does not measurably improve the prediction.

### *Assessing the Predictive Ability of the Model*

A classification table may be used to assess the usefulness of a model-based predictive procedure, but such a table depends on the choice of boundary values used to separate students into the two predicted groups. This arbitrariness may be avoided by examining Summer's  $D_{yx}$  [Leach, 1979].

Among randomly assigned pairs of students, one who was winged and one who has attrited, denote  $P_c$  as the probability that the model correctly assigns the larger probability of being winged to the winged student (thus correctly discriminating the winged from the attrite in the pair). Also, let  $P_d$  denote the probability that the model incorrectly assigns the larger probability of being winged to the member of the pair who attrites. The nonparametric correlation, Summer's  $D_{yx}$ , estimates the difference between the probability that the model correctly predicts the winged member of the pair and the probability that it incorrectly predicts the winged member:  $D_{yx} = P_c - P_d$ .

The values of Summer's  $D_{yx}$  for the two models are:

$$\text{Model I: } D_{yx} = .636 - .364 = .272$$

$$\text{Model II: } D_{yx} = .654 - .346 = .308$$

From the estimates of  $P_c$  and  $P_d$ , we see that the models correctly predict the winged member of the pair nearly twice as frequently as they incorrectly predict the winged member. These measures are overly optimistic, however, because the models' predictive ability is assessed using the same data that were needed to build the data. This problem necessarily makes more difficult the evaluation

of the performance of the statistical models to predict success on a selected population. It would have been better had the models been tested in the original population of all applicants to flight school. A more honest appraisal of the success of the model on future selected populations would be provided in a double cross-validation.

#### *Double Cross-Validation*

In order to check the validity of the estimates and to better assess the predictive usefulness of the model, the data set was randomly divided into two equal subsets. The two models were estimated using the data from each subset, alone, and then comparing the maximum likelihood estimates of the parameters. The estimates of the significant variables A and A'P, are displayed in Table 4.

- PLACE TABLE 4 ABOUT HERE -

The estimates of the visuospatial coefficient seem relatively stable across subsets in both models. By contrast, the interaction between verbal-sequential and visuospatial variables does not seem stable. This suggests that the visuospatial scores continue to be an excellent predictor of success, but that the contribution of the interaction is more suspect.

The measure of predictive ability, Summer's  $D_{yx}$ , assesses the ability of the models by using the data of one subset to predict the winged individuals in the other subset (Table 5). In these cases with reduced number of subjects, neither model appears to be better for predictive purposes. Both correctly predict the winged individual in the pair on the average 21% more frequently than they fail to correctly classify the pair.

- PLACE TABLE 5 ABOUT HERE -

## DISCUSSION

There was a significant difference in performance on visuospatial tests between Student Naval Aviators who were graduated from the training program (received their "wings") and those who left the program by choice or through flight or other failure ("attrites"). This was true whatever the specific program the pilot entered: combat (strike), helicopter, and propeller-driven (maritime). Verbal-sequential tests did not distinguish the attrites from the winged subjects nor among the 3 types of pilots, although the subjects in the combat group tended to be better overall. These results replicate a previous study with Israeli Air Force pilots [Gordon, Silverberg-Shalev, & Czernilas, 1982]. In the Israeli pilot study, subjects who were transferred out of the combat training program entered either the navigator or helicopter training program. (This is not the same selection process placing aviators into a particular "pipeline" in the present sample. Decisions are made on a number of criteria and not on failure in the combat program.) The Israeli fighter pilots were significantly better on the visuospatial tests -- three out of four of the same tests used in this study -- than the other 2 groups.

It is not remarkable that pilots favor visuospatial skills, nor is it surprising that those who were the more successful had the better performances on these tests. However, it is important that differences in visuospatial skill occurred after the normal selection processes in both armed services. The results of these studies strongly suggest that visuospatial tests of the type on the Cognitive Laterality Battery can be used to eliminate potential flight fail-



ures. Since these results were obtained on a pre-selected and therefore restricted population, it remains to be seen what the actual prediction would have been on the population of applicants prior to selection.

The results suggest that considerably more potential attrites could have been eliminated than potential winged aviators if the average visuospatial score ( $A=0$ ) had been used as a cut-off point even in the restricted population. At this point, 22% of the attrites (29 of 130) but only 7% of the winged would have been eliminated. The ratio of hits versus false positives is 3:1.

With hindsight of the data collected (See Figure 1), the best cut-off point appears to be at the mean visuospatial performance of the attrites ( $A=0.420$ ). Note that this performance is above average compared to the normative group but 0.25 standard deviation lower than the winged average. At this higher cut-off point, more than half of the eventual attrites ( $67/130 = 52\%$ ) would have been eliminated but only about a fourth ( $133/470 = 28\%$ ) of the eventual winged aviators would have been eliminated. In this case, the ratio of hits to false positives is 2:1. The acceptable number of false positives cannot be answered by these data. Much would depend on the benefit in saved training dollars by denying potential attrites from entering the program compared to the cost of preventing potential aviators from getting their wings. The quality of the false positive aviators allowed to enter the program would also be a factor.

Additional information with regard to who is likely to succeed in the pilot training program was obtained from the logistic regression model. Although the verbal-sequential skill did not distinguish

between the attrite and winged group, it did appear to interact with visuospatial ability. In particular, it was found from the model, and confirmed by the data, that increasing verbal-sequential skill actually hurt one's chances of being winged for high visuospatial ability but helped for low visuospatial ability. Cross-validation of the model in subsets of the data was found to be less stable for the interaction than the effect of the visuospatial skill. However, if high verbal skills do indeed hinder one's chances of getting wings in individuals with high visuospatial skills, then insight as to the reasons would be helpful. At this point, only speculation and anecdotes are available. Flight instructors often say that good pilots "fly by the seat of their pants". This would not likely characterize a highly verbal individual whose presumed analysis of every move may interfere with superior spatial reasoning.

The main limitation of this study for use in pilot selection is that these data were collected on a restricted population. That is, the student aviators in the study had already been selected by Navy criteria. This fact makes it difficult to speculate how the Cognitive Laterality Battery would have fared against the established criteria prior to selection. Some of the criterion test scores were available for 2 qualifying tests -- a general ability test and a spatially-loaded test. In the restricted population, these did not distinguish the winged from the attrites as well as the visuospatial score, nor did they enter significantly into the regression model. At worst, then, the tests of the Cognitive Laterality Battery appeared to be useful as a "second cut" in reducing the number of potential attrites without seriously reducing the number of potential winged aviators. At best, a study on applicants prior to selection

may show the specialized tests of cognitive function to be a better predictor of attrites from the training program than the currently used measures. Since the cognitive tests have been selected as valid measures of brain function, they would offer additional insight into the cognitive profile required of a high performance aviator.

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TABLE 1. ANALYSIS OF VARIANCE

MODEL I			
SOURCE	DF	CHI-SQUARE	SIG.PROB.
<hr/>			
INTERCEPT	1	19.90	.0001
A	1	24.12	.0001
P	1	3.21	.730
AP	1	4.43	.0352
LIKELIHOOD RATIO	596	597.63	.4735
GOODNESS-OF FIT			

MODEL II			
SOURCE	DF	CHI-SQUARE	SIG.PROB.
INTERCEPT	1	.49	.4841
HAND	1	2.18	.1399
SYMDIG	1	2.87	.0902
A	1	20.14	.0001
P	1	2.73	.0984
AP	1	4.90	.0269
LIKELIHOOD RATIO	594	592.80	.5062
GOODNESS OF FIT			



TABLE 2. MODEL BASED PARAMETER ESTIMATES

## MODEL I

PARAMETER	ESTIMATE	STANDARD ERROR
-----------	----------	----------------

INTERCEPT	.6740	.1511
A	1.1532	.2348
P	.4488	.2504
AP	-.6839	.3248

## MODEL II

PARAMETER	ESTIMATE	STANDARD ERROR
-----------	----------	----------------

INTERCEPT	-.4032	.5793
HAND	.2132	.1444
SYMDIG	.0188	.0111
A	1.0837	.2415
P	.4214	.2550
AP	-.7411	.3348

TABLE 3. CONFIDENCE INTERVALS FOR ADJUSTED ODDS RATIOS  
(FIGURES 2 AND 3)

Percentiles of verbal-sequential or visuospatial ability	For two aviators differing by 1.0 s.d. visuospatial ability		For two aviators differing by 1.0 s.d. verbal-sequential ability	
	ODDS RATIO	CONF. INT.	ODDS RATIO	CONF. INT.
5	1.47	(1.009, 2.149)	2.20	(1.528, 3.175)
25	1.15	(0.922, 1.443)	1.82	(1.423, 2.280)
50	1.00	(0.815, 1.239)	1.52	(1.299, 1.958)
75	0.87	(0.671, 1.141)	1.37	(1.069, 1.755)
95	0.76	(0.524, 1.091)	1.12	(0.763, 1.648)

TABLE 4. MODEL BASED PARAMETER ESTIMATES FOR BOTH SUBSETS

MODEL I		
PARAMETERS	A	A'P
Subset 1	1.2656	-1.2588
Subset 2	1.0927	-.1779

MODEL II		
PARAMETERS	A	A'P
Subset 1	1.0837	-.7411
Subset 2	.9939	-.2211

TABLE 5. SUMMER'S  $D_{YX}$  FOR THE 2 SUBTESTS

Model	Subset used to estimate parameters	Subset used to estimate parameters	Summer's $D_{YX}$ $P_C - P_P = D_{YX}$
I	1	2	.578 - .422 = .156
I	2	1	.634 - .366 = .268
II	1	2	.585 - .415 = .170
II	2	I	.627 - .373 = .244

## FIGURE CAPTIONS

Figure 1: Distributions of visuospatial scores for attrites and winged aviators. Note cut-off points at the normative average ( $A=0$ ) or the attrite average ( $A=0.420$ ) would have eliminated many more potential attrites than winged.

Figure 2: Odds ratio of 2 subjects differing by 1 standard deviation of visuospatial skill over a range of verbal-sequential ability. The odds always favor the subject with the higher visuospatial ability but less so for high verbal-sequential skill.

Figure 3: Odds ratio of 2 subjects differing by 1 standard deviation of verbal-sequential ability over a range of visuospatial skill. Odds tend to favor the subject with the higher verbal-sequential skill for low visuospatial ability but favors the subject with lower verbal-sequential skill for high visuospatial ability.

Figure 4: Odds of being winged for 3 levels of verbal-sequential scores,  $P$ , over a range of visuospatial skills. Note that the odds increase with visuo-spatial skill for each level of verbal-sequential ability.

Figure 5: Odds of being winged for 3 levels of visuospatial scores,  $A$ , over a range of verbal-sequential abilities. Note that the odds differ depending on the level of visuo-spatial skill.

Figure 6: Predicted and observed ratios of winged/attrites for the lower, middle and high thirds of visuospatial and verbal sequential skill.

## FOOTNOTES

<sup>1</sup> Attrition, attrite, (etc.) are terms used by the Navy to refer to the state of leaving the training program (attrition), a person who leaves the program (an attrite), and the act of leaving the program by choice (to attrite) or by force (to be attrited).

# DISTRIBUTIONS OF ATTRITES AND WINGED ON VISUOSPATIAL ABILITY

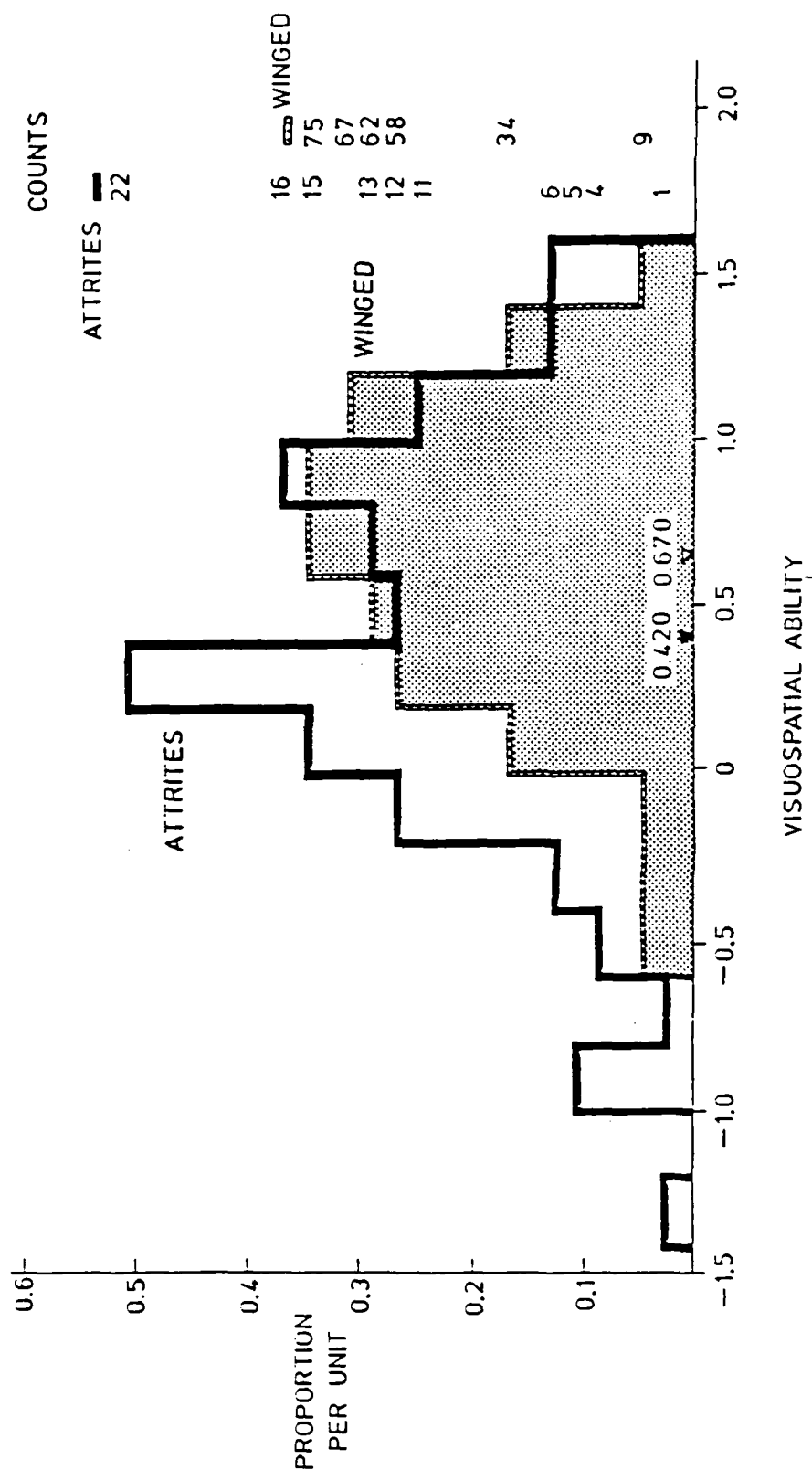


FIG. 1



RELATIVE ODDS OF BEING WINGED FOR 2 STUDENT  
AVIATORS DIFFERING BY 1.0 SD OF VISUOSPATIAL SKILL

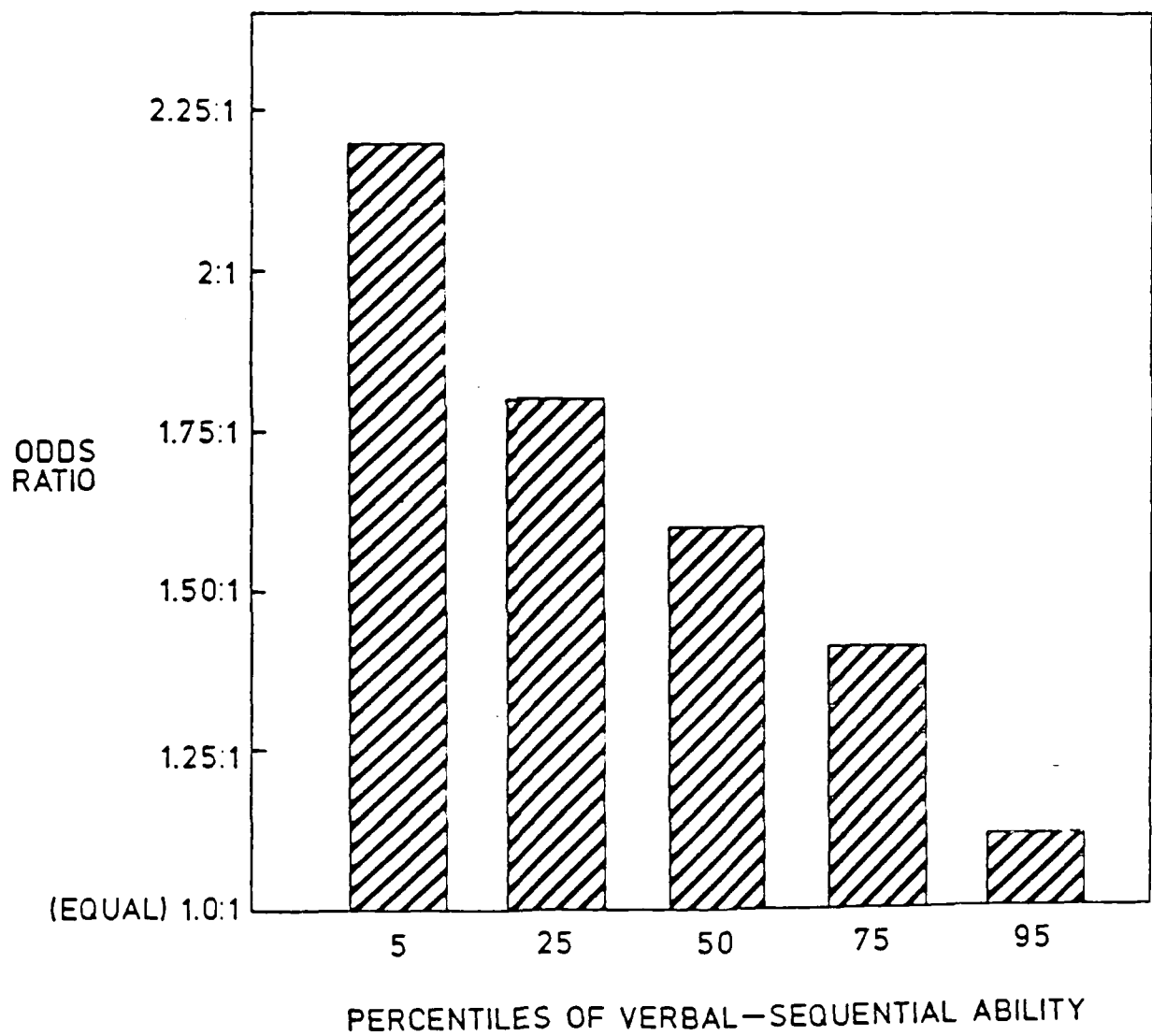


FIG 2

RELATIVE ODDS OF BEING WINGED FOR TWO STUDENT AVIATORS  
DIFFERING BY 1.0 SD OF VERBAL-SEQUENTIAL ABILITY

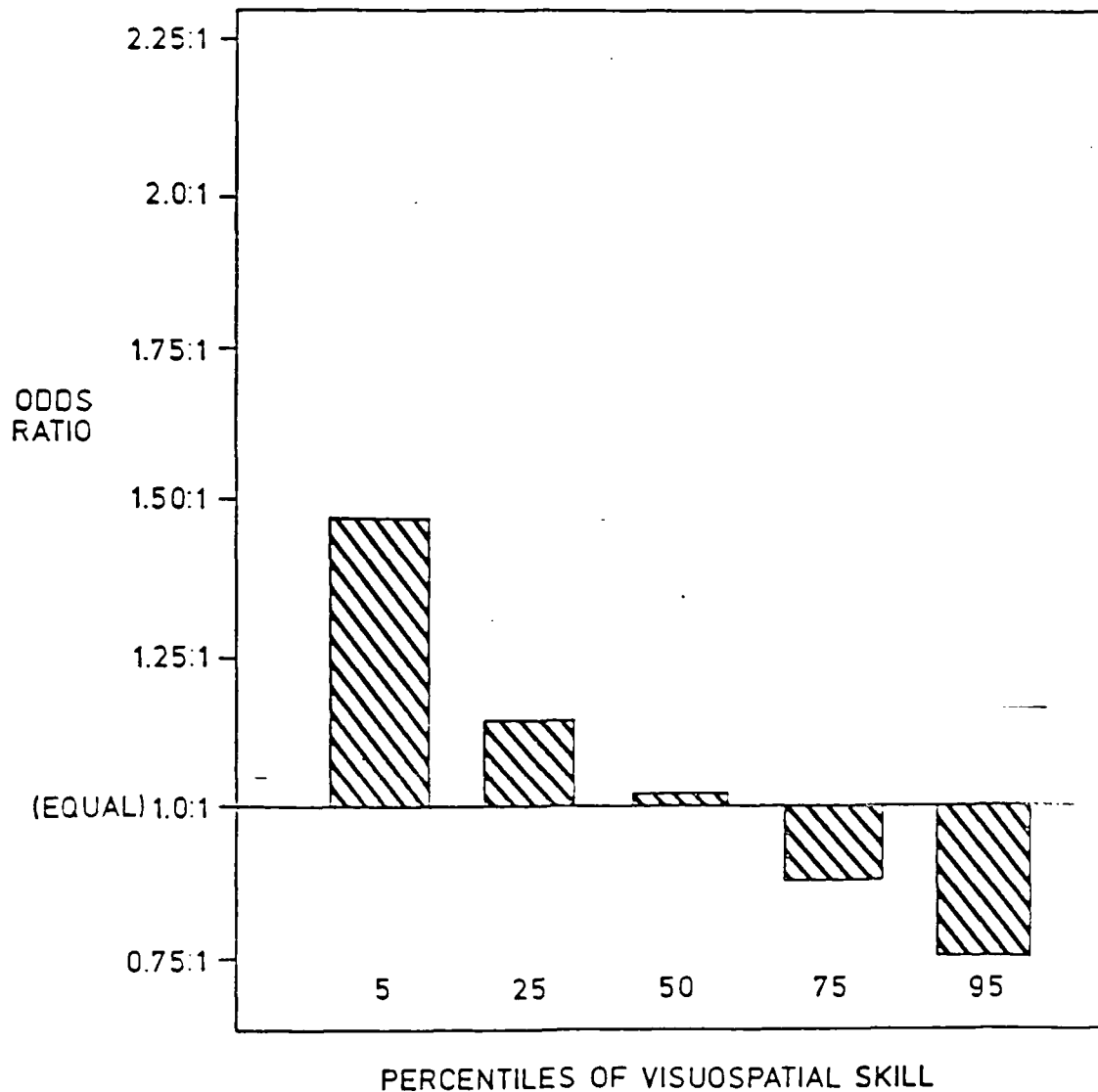


FIG 3

PROBABILITY RATIOS FOR 3 LEVELS OF  
VERBAL-SEQUENTIAL ABILITY FOR 5 PERCENTILES OF VISUOSPATIAL SKILL

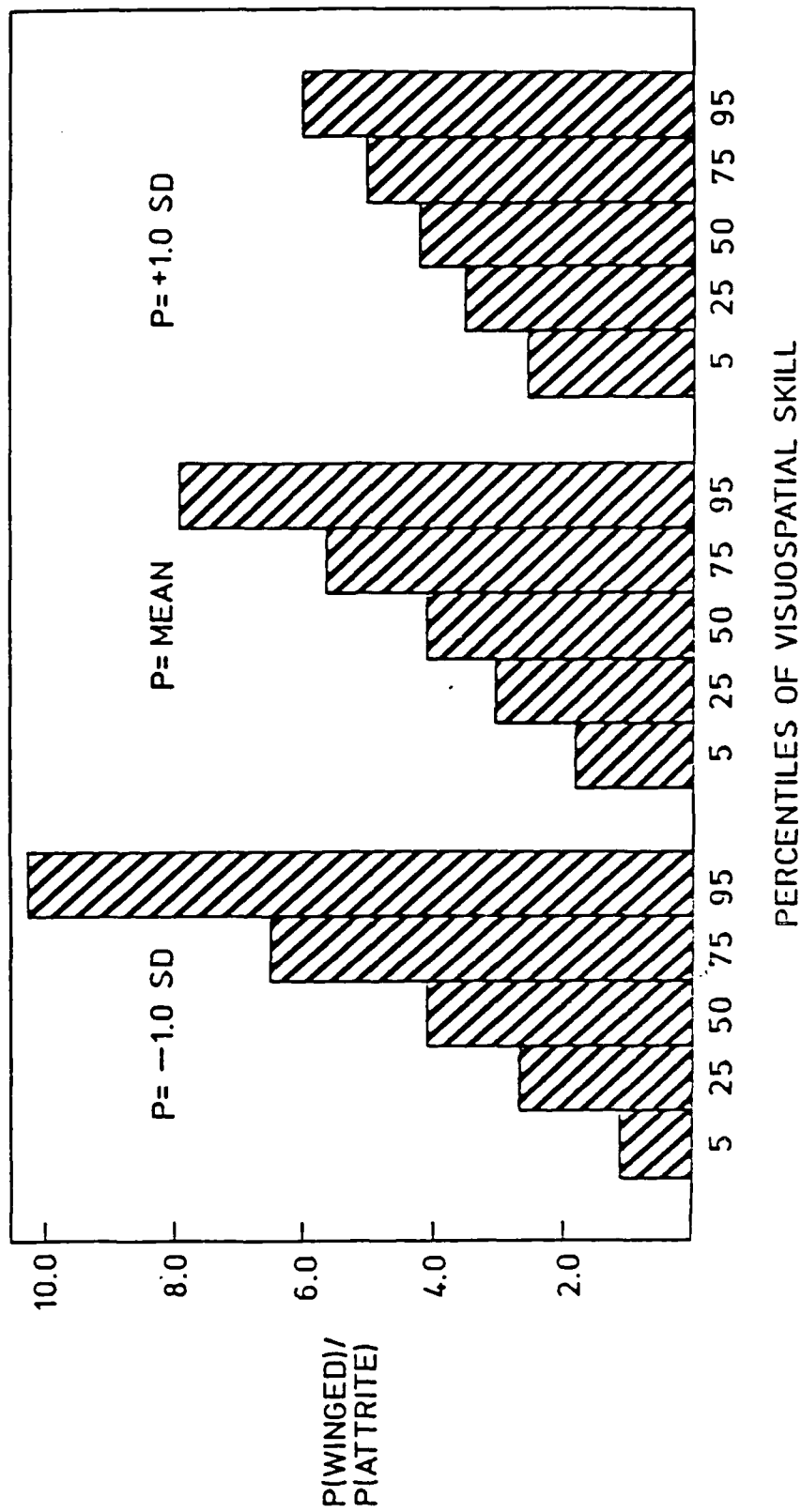


FIG 4

PROBABILITY RATIOS FOR 3 LEVELS OF  
VISUOSPATIAL SKILL FOR 5 PERCENTILES OF VERBAL-SEQUENTIAL ABILITY

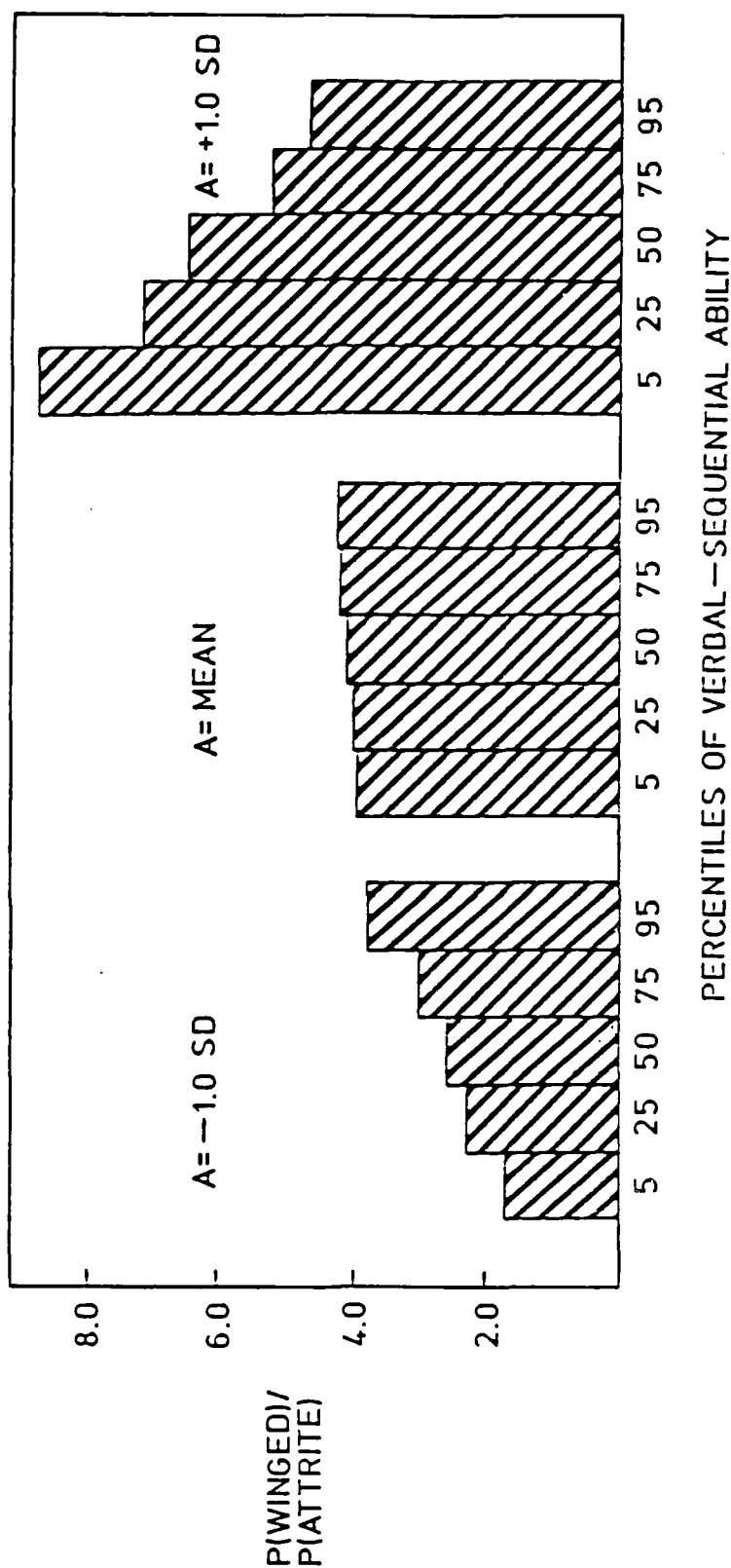
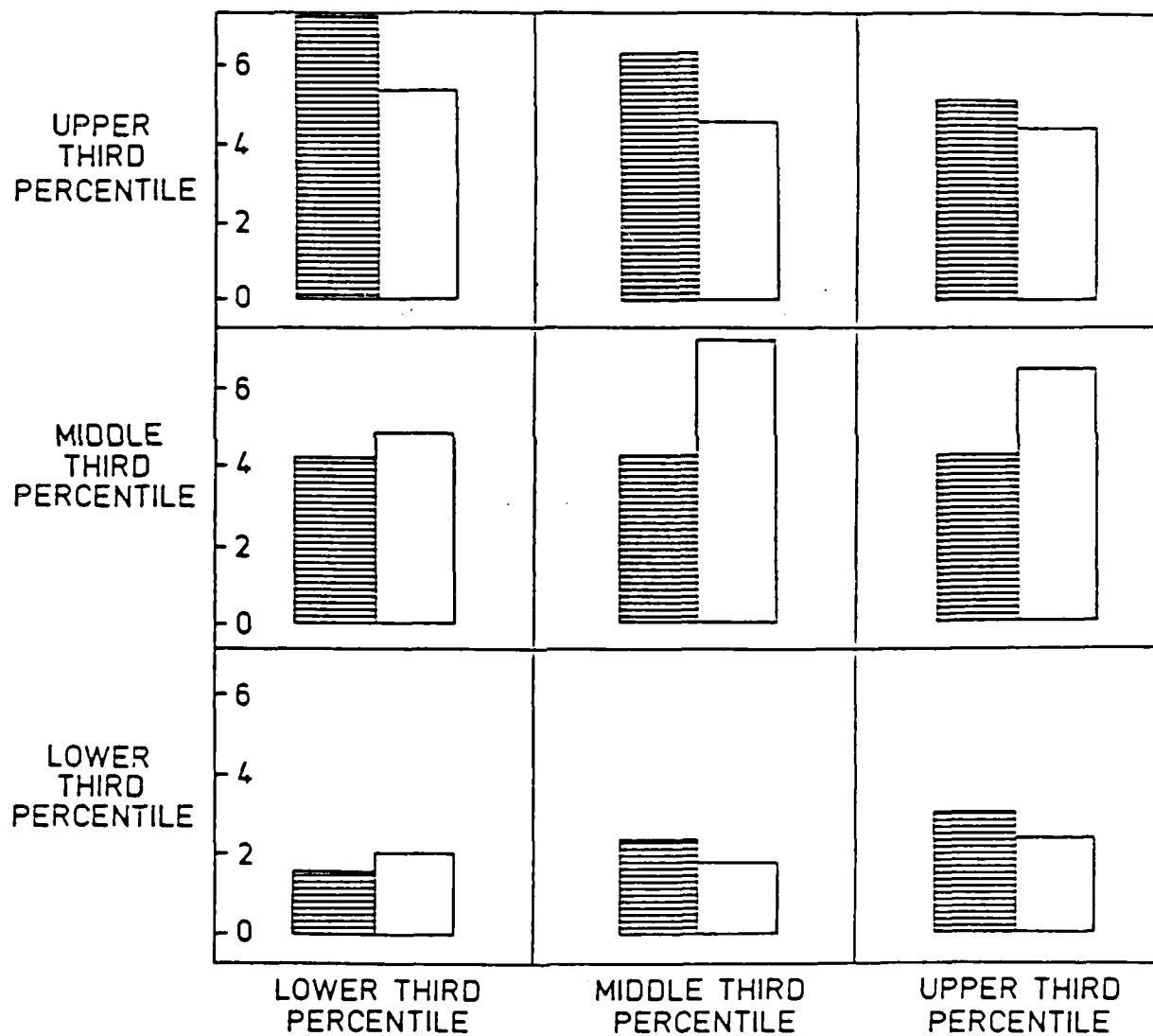


FIG 5

PREDICTED AND OBSERVED ODDS OF BEING WINGED AT  
VARIOUS LEVELS OF VISUOSPATIAL AND VERBAL-SEQUENTIAL ABILITY

VISUOSPATIAL  
SKILL



VERBAL-SEQUENTIAL ABILITY

 PREDICTED
  OBSERVED

FIG 6

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